Reprinted from:
Engineering Geology Practice in Southern California
AEG Conference 1992
Long Beach, California

GEOTECHNICAL APPLICATIONS OF INFRARED OBLIQUE STEREO PHOTOGRAPHY

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INTRODUCTION

Two general areas of aerial photography will be discussed. The first is what affects the appearance of photographic images, and how we can control those aspects to improve information quality. The second area will cover some of the basic interpretations that can be made from this improved image quality with particular emphasis on oblique stereo infrared photography. Oblique stereo photographic images, in particular infrared images. have the capability of being one of the more significant investigative support tools available to the geotechnical professionals, and yet they are the least used and most misunderstood forms of visual information in use today. Generally, the term infrared photography produces a response from most professionals that heat variations are not significant in their investigation, or oblique images are useful for office walls, but not as an investigative tool. The fact is that infrared photography has nothing to do with heat and oblique aerial photography has as many capabilities and uses as the common vertical image. To put this statement in context it is necessary to define some terms and limits for Standard Color vs. Color Infrared photography, and oblique stereo imaging.

WAVELENGTHS & FILM

The zone of electromagnetic radiation usually referred to as the visible light spectrum, has wavelengths ranging from approximately 400 to 700 nanometers (Fig. 1). The short end of this zone consist of wavelengths that our eyes perceive as the color blue. As one proceeds up the wavelength scale one passes through green, yellow. orange, and red, which is the longest wavelength the human eye can perceive. Beyond the short end of the visible spectrum is ultraviolet. The effects of these wavelengths on photographic images are most apparent as a hazy skyline in standard color photographs. This effect is produced from ultraviolet and blue wavelength light scattering on airborne

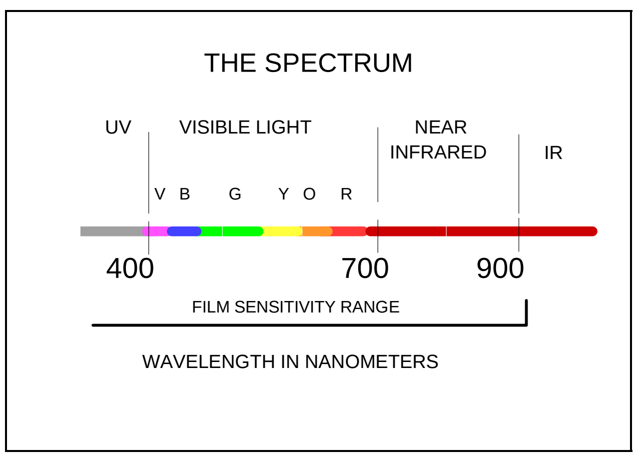

Figure 1

particles or moisture. On the opposite end of the visible spectrum is the infrared zone starting at approximately 700 nanometers wavelength. These infrared wavelengths do not produce sensible heat until they attain a wavelength of approximately 1350 nanometers. Imagery that is generated as a function of heat radiation from the longer wavelength part of the infrared spectrum is generally produced by a computer. This type of imagery is referred to as scan imagery. The computer has a series of scanners, each of which is sensitive to a specific wavelength or group of wavelengths. The computer receives information from the scanners. and then builds an image based on preprogrammed criteria. This type of imagery has many uses, but it is not infrared photography.

Infrared photographic images are recorded directly on a film base with specific wavelengths of reflected visible and near infrared electromagnetic radiation. Near Infrared is a zone just outside of the long end of the visible spectrum, and the lower end of the infrared range. This zone has wavelengths ranging from approximately 700 to 900 nanometers. This section of the infrared range is not sensible heat. but it can be thought of as an invisible extension of the visible light spectrum. This is why infrared images should not always be equated with heat. If infrared films were heat sensitive they could not be handled for camera loading, as body heat would fog the film. Some type of refrigerated and insulated camera would be needed to shoot the film. So, what actually exists is a film that is not heat sensitive, and has been specially designed to respond to only the near infrared part of the infrared spectrum, and all shorter visible wavelengths. The film was developed during the Second World War as the military wanted a film that would differentiate between natural vegetation and camouflage in the field. It was determined that normal healthy chlorophyll in plants reflect the near infrared wavelengths. This reflectivity provides some significant interpretative parameters that will be discussed later. As the film is also sensitive to all of the shorter wavelengths, including ultraviolet, it is recommended a number 12 yellow filter be used. This filter restricts the passage of blue light and shorter wavelengths that tend to degrade the image resolution, and shift colors. It is important to use the number 12 yellow specified by the film instructions.

There are several types of color infrared film available, and consideration should be given to which one to use for best results. The only color 35mm infrared used in the United States today is Ektachrome Infrared, which is an E-4 process film. Even though most geologists have access to a 35mm camera, and the processing is not impossible to find, this format is not recommended because the 35mm format is just too small for good aerial photos. The format limitations are compounded by the fact that the E-4 process is an older process that is in little use today, which means the film will have to be shipped to some major processing center with E-4 capabilities. The turn around times varies from four to six weeks. The commonly used infrared films are designated as aerial infrared and are available in negative and positive (Color Slide) film types. The smallest film size available is 70mm roll film, followed by 4 X 5 inch format films and larger. Even though a medium format camera with 70mm back capabilities is not the average camera of geotechnical professionals, it is still the best all around system for low elevation aerials, ease of handling, transport, versatility, and image economics.

Negative-type films tend to be less expensive than positive type films. and the prints generated from negatives are also generally less expensive than prints from positives. However, positive (color slide) films are superior for geotechnical applications. Positive do not require prints to view and evaluate images. This capability eliminates the need, as well as the cost, of printing every single frame. It also allows direct evaluation of original images. These originals are superior in resolution and image quality compared to prints produced from any type of film. There are no photographic papers on the general market capable of reproducing all of the detail and color variation that exist in an original film. This positive infrared film is called Aerochrome Infrared 2443 and is available from authorized Kodak professional film dealers.

Aerial infrared films do not have standard ASA ratings that can be used to set camera light meters for appropriate exposure. In fact, there is no standard exposure for all conditions, and it will vary widely depending upon a number of factors. If a qualified professional experienced with infrared films is not being hired for your project shooting, then start with an ASA of 100 and experiment to establish norms for various conditions including the following:

1. Type of light metering system being used.
2. Percent of ground vegetation cover.
3. Percent and type of lithologies exposed.
4. Sun angle/Time of day.
5. Percent of horizon or skyline included in picture (Oblique).
6. Filtration used over lens.
7. Light transmission characteristics of optics.

There are also a number of secondary image enhancements associated with positive color infrared films. Positive films tend to be higher contrast than negative films. Many times there are ground features with subtle light reflection differences that are not recorded by lower contrast negative type films or they become lost in reproduction. This pumped up contrast also affects color difference separation which can add additional interpretative capabilities.

If positive films are so much better for airphoto interpretation, why don't the aerial companies use positive films instead of negative films as their standard? The answers are money, ease of use, and the primary application was not planned for use by geologists. As indicated earlier, negative films are easier to shoot, and color prints must be generated for analysis. The ease of use factor is that negative films have a very wide exposure latitude compared to positive films. This means that best exposure can be missed by several F-stops with negative films, and you will still be able to generate a good color print from the negative. If you miss best exposure on a positive film by more than one half F Stop, there will be substantial loss in image quality. If an aerial company has to re-fly a project due to bad exposure, this costs them money, and the chance of getting poorly exposed film on negatives is substantially less compared to using positive films. The primary planned use of airphotos for more than fifty years has been cartographic, or map making applications. The map making industry and the equipment they use has been designed to use negative type films and their associated prints. Aerial photographic images seldom, if ever, are preplanned specifically for geotechnical interpretation. The overall commercial photography industry has also moved almost exclusively to positive films.

Botany might be considered to be a little out of place here, however it is extremely important. Geologist have known for years that many formations or their contacts could be mapped by the type of vegetation growing on them. The chlorophyll structure is one of the wonders of nature that allows plants to generate the nutrients, in this case glucose, that feeds the plant. The plant extracts carbon dioxide (CO_2) from the atmosphere and water (H_2O) from the ground or air. The chlorophyll structure combines the carbon and hydrogen from the two molecules to produce a form of sugar or glucose. Let's extend the thought processes one step further keeping in mind the responses of near infrared light to chlorophyll, the function of chlorophyll. and structural geology.

1. The more chlorophyll a plant has, the more water it needs to function.

2. Plants tend to seek out ground and groundwater conditions that are most conducive to its long term growth and development.

3. Broad leaf varieties of plants have abundant chlorophyll and require abundant and long term water supplies to survive, as compared to desert varieties that have little to no leaf structures and only bloom for short periods each year.

4. Chlorophyll is the most sensitive indicator of a plants health. With adequate water and basic nutrients the chlorophyll will have high activity and therefore high reflectivity in the near infrared.

5. Geologic structure controls groundwater, and water controls vegetation.

APPLICATIONS

With theses concepts in mind let's find a landslide and a fault that cannot be seen in the field, and that do not show up in standard color or black & white photographic images. Landslides produce ground rupture along their boundaries and normally produce various types of perched groundwater or springs. Even though the visible surface expression will change or even be obliterated with time, the subsurface conditions remain. Head and lateral grabens will infill with colluvium, and many times produce perched water conditions that provide a reservoir for months, or years. These areas of abundant near surface water will attract appropriate types of vegetation. The vegetation in these areas of good water supply will be healthier and therefore have a higher near infrared reflectance than nearby plants of a similar type with less water, or plants of other varieties with smaller leaf structures. These structural groundwater controls of vegetation can be made visible to the human eye with infrared films. These trends, lineaments. and curvatures can then be interpreted.

Aerial photograph number 1 is a frame taken from a series of oblique stereo images in southern Orange County, California. The area is mostly siltstone of the Miocene Capistrano Formation capped by terrace deposits. The creek channel is marked by vivid red vegetation due to the abundant water supply stored in alluvial materials. Just upslope and parallel to the channel, a well defined lineament can be seen. Upslope of the lineament the vegetation is thicker and larger with prominent bushes showing vivid red coloration. Below the lineament. and downslope, the vegetation is smaller with little to minimal red vegetation reflections. The lineament is a fault that is generating a ground water barrier that restricts the flow of water to the downslope side of the fault. The abundant water backing up on the upslope side of the fault attracts vegetation forms that are broad leaf types with abundant chlorophyll, and therefore high infrared reflection. The right visual limit of the fault terminates at the boundary of an ancient landslide. The lateral boundaries and the head graben are marked by large vivid red vegetation. A bulge in the channel marks the toe of the feature. Neither the fault or the landslide were detected during an earlier geotechnical investigation.

The basic interpretations can be extended in a number of different directions and over a variety of ground conditions. The result is that "invisible" ground features can be detected and delineated. An extensive knowledge of plants and their environments is not a necessity, however, the more knowledge you have the better your interpretations will become.

There is no one time of the year that is best for all conditions. The number of detectable features can vary weekly, monthly, or yearly. Some features drain slowly with large reservoir capacity and control vegetation year round. However, this same feature may be obscured in the rainy season in a high rainfall climate as all surrounding vegetation is also well watered and healthy. This feature may only be visible during the middle or late part of the dry season. Other features, in the same area, may drain quickly and leave no trace in middle or late summer. In a somewhat dryer climate many features may be seen best during the middle or late rainy season. For these reason and others, flight time considerations are important. The best possible alternative, based on economics, is to fly the site at least two times during the year with a six month separation between flights. If time and economics permit, make additional flights. Each flight should be preplanned and areas of priority detected in previous flights targeted for special shooting.

Potential and old debris flows can also be detected and delineated in much the same way. These features tend to build up in old channels or pockets on hillsides with a variety of slope angles and sizes. These alluvial or colluvial structures are normally loose and porous compared to surrounding bedrock materials and they transmit and trap water. These perched water conditions also control vegetation and are often found along the boundaries or within old landslides that obscure old slides on standard photographic images. Other potential debris flows, like deep weathering areas with subsurface water, will show many of the same earmarks described above.

Aerial photograph number 2 shows a series of these potential debris flow structures. The right hand wall of the canyon is marked by a number of linear and pocket plumes of high reflection vegetation. The life of these reflections, like landslides, will vary with size, storage capacity, water supply and climate. Anytime steep natural hillsides are to be adjacent to developed areas, they should be investigated for potential debris flows. There is also an unrepaired reactivated ancient landslide visible in the head of the canyon. This landslide, like many landslides occurring in developed areas today, are not new landslides. They are reactivated ancient landslide that were missed by standard investigation techniques.

GROUND WATER AND LITHOLOGY

All of the objects we see as color are a combination of both reflection and absorption of light. Near Infrared is totally absorbed by water. This characteristic means that areas with near surface groundwater, adequate to produce a moisture variation at surface, will photograph a little darker on infrared film, than the same ground condition nearby with no surface moisture. This is an additional interpretative parameter to add to the above infrared capabilities. Often high or perched groundwater conditions will not only produce the deep red vegetation reflections, but also darker areas on the ground indicating the near surface limits of the water body. In some areas there may be no vegetation and only the slightly darker areas marking groundwater springs or seepage.

The combined effects of vegetation near infrared reflection, increased contrast, and infrared absorption by water, also makes infrared films an excellent tool for delineating and mapping land/water interfaces in heavily vegetated areas. The deep red color of vegetation and the dark blue to black of water is a substantial contrast improvement over conventional color photos that show green and dirty green or brown.

Rock types with contrasting infrared reflections can add an additional interpretative parameter. Rock types containing quartz, like sandstone, reflect more near infrared than siltstone or claystone. Limestone produce a high reflection like sandstone. These variations in rock reflections may produce lineaments on ground surfaces that are not visible to the eye, standard color, or black and white imagery forms, but can be seen in color infrared. These lithologic variations may be produced as the slide block displaces bedding structures, or as the graben infills with colluvium that may contrast with adjacent slide debris or bedrock. This type of variation is very useful in finding faults as the lineaments become longer and easier to see. For landslides it may provide that one additional piece of information necessary to make an interpretation.

USE OF OBLIQUE STEREO PHOTOGRAPHS

It has long been the opinion of most professionals that vertical aerial photos are the prime investigation image form, and that oblique aerials are mostly useful as office displays. The fact is that for every piece of information obtained from a set of vertical images, two to three pieces of information can be obtained from a set of planned stereo oblique images. The same ratio applies in available applications. This does not mean that verticals should be replaced by obliques. It is obvious that there are important applications in verticals that cannot be replaced by oblique images. Oblique aerial imagery is just one more tool that must be added to the geologic tool box. Oblique aerial images can be generated in stereo, just like verticals. The biggest single advantage of an oblique geotechnical flight over a vertical flight is perspective. Perspective, in this case, is a position of view. Vertical images have only one perspective relative to the ground, no matter how many frames are generated. Obliques have an infinite number of possible perspectives. Many ground features do not show up in vertical images simply because the angle of view is wrong to see the shape or texture of the feature. This capability has been utilized, in a limited way, by geologists in the form of low sun angle photography. In this case lighting is allowed to move to a very different position from normal, and in some cases oblique photography was even used. This perspective benefit associated with oblique images increases significantly as terrain relief increases, and is optimized with stereo viewing. As terrain relief increases, vertical exaggeration increases and many features located in those areas become obscured in vertical images. Oblique stereos are the best image form to use on projects that have vertical or near vertical faces to investigate. These types of projects include coastal bluff studies, dam and reservoir sites, and any kind of steep high relief terrain. For every feature detected in a vertical flight, at least one more feature will be found in a planned oblique stereo flight. This translates to at least 100% improvement in information yield. If any of those oblique detected features are major hazards, that would have gone undetected until grading or development, substantial amounts of time and money are saved. Therefore the economic benefits to clients far outweighs the small cost of generating such imagery. Other secondary benefits associated with oblique image flights are the ease of varying scales in photos without substantial cost increases, and improved communications and documentation. Vertical aerial companies charge for a new flight each time they change scales. Technical photographers shooting from helicopters seldom charge extra for elevation changes, and a helicopter is the best method of shooting oblique stereo photos. Non-professionals do not visualize vertical images like most geologists. Obliques are superior when communicating with lay groups or documenting vertical features. It is a rare project that cannot benefit from planned geotechnical oblique stereo photos.

The aspects of relatively expensive cameras, special shooting techniques, and films that are somewhat difficult to use should not be allowed to deter a geologist from attempting these capabilities. The difference between using a regular commercial photographer and placing these photographic and interpretative skills in the hands of a geologist, is literally like night and day. The geologists ability to preplan imagery based upon geotechnical skills, and then evaluate site conditions during flight and make appropriate adjustments is critical for best results.

Airphoto #1

Airphoto #2